

***BIOMORPHIC EXPLORERS &
BIOMORPHIC MISSIONS***

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BIOMORPHIC EXPLORERS

- **COOPERATIVE BEHAVIORS OF VERSATILE MOBILE ENTITIES**
 - **INTERDEPENDENCE**
 - **EFFICIENT USE OF NATURAL AND EXISTING RESOURCES**
- **TO PROVIDE EXTENDED SURVIVAL AND USEFUL LIFE OF THE ROBOTS TOWARDS FULFILLMENT OF THE MISSION/APPLICATION**

BIOMORPHIC EXPLORERS

- **SMALL, DEDICATED, LOW-COST EXPLORERS THAT CAPTURE SOME OF THE KEY FEATURES OF BIOLOGICAL EXPLORERS**
 - Small... 100-500g (useful space exploration functions are implementable* using this mass)
- **CONDUCTED WORKSHOP, AUG 19-20, 1998**
 - **SPONSORED BY NASA/JPL**
 - **VERY SUCCESSFUL; OVER 150 PARTICIPANTS**

* JPL DOCUMENT D-14879A, JPL DOCUMENT D-16300A,
JPL DOCUMENT D-16500, AUTHOR: SARITA THAKOOR

BIOMORPHIC EXPLORERS

- **KEY FEATURES**
 - **VERSATILE MOBILITY:** aerial, surface, subsurface, and in fluids
 - **ADAPTIVE, CONTROLS**
 - **BIOINSPIRED SENSOR SUITE**
 - 3D NEURAL NETWORK PROCESSOR FOR IMAGE RECOGNITION, CLASSIFICATION & TRACKING
 - **BIOMORPHIC SENSOR FUSION**
 - **BIOMORPHIC COMMUNICATIONS**
 - **BIOMORPHIC COOPERATIVE BEHAVIOR, DISTRIBUTED OPERATIONS**
 - **BIOMORPHIC ENERGY GENERATION/ CONVERSION**

Biomorphic Explorers: Classification (Based on Mobility and Ambient Environment)

Biomorphic Explorers

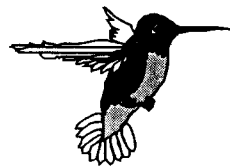
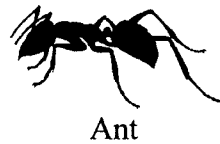
Aerial

Surface/Subsurface

**Biomorphic Flight
Systems**

**Biomorphic Surface
Systems**

**Biomorphic Subsurface
Systems**



Examples of biological systems that serve as inspiration for designing the biomorphic explorers in each class

Biomorphic Explorers: Classification (Based on Mobility and Ambient Environment)

Biomorphic Explorers

Aerial

Biomorphic Flight Systems



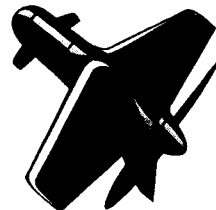
Seed Wing Flyer (60 g)



Ornithopter



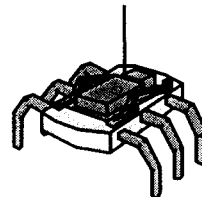
Glider (75 g)



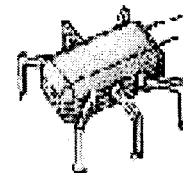
Powered Flyer

Surface/Subsurface

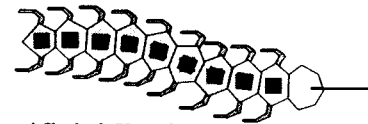
Biomorphic Surface Systems



Hexapod
(1-2 kg)



Reconfigurable
Legs/Feet



Artificial Earthworm

Biomorphic Subsurface Systems



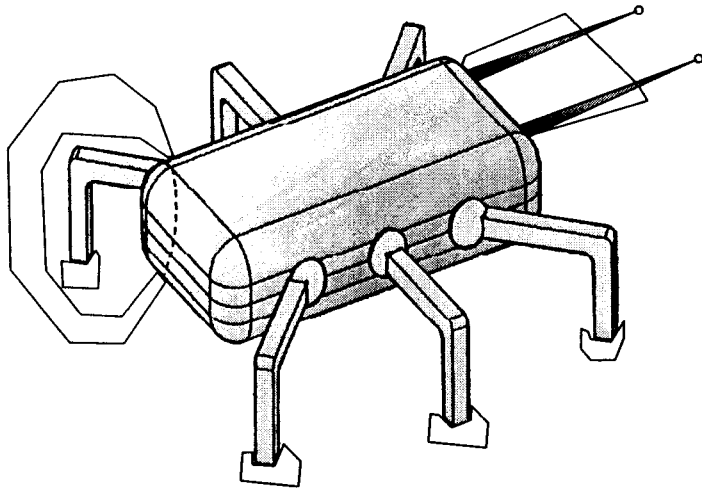
Artificial Jelly Fish



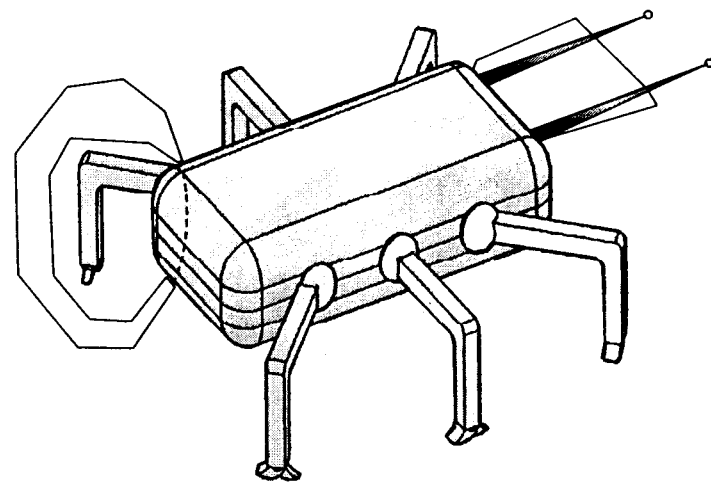
Worm Robot (85 g)

Candidate biomorphic explorers on the drawing board, with mass of design under study in 1998 in parentheses

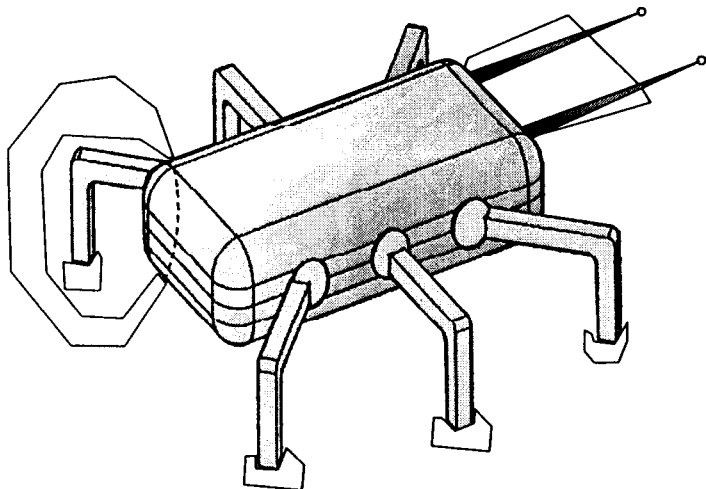
MULTITERRAIN RECONFIGURABLE LEGGED EXPLORER



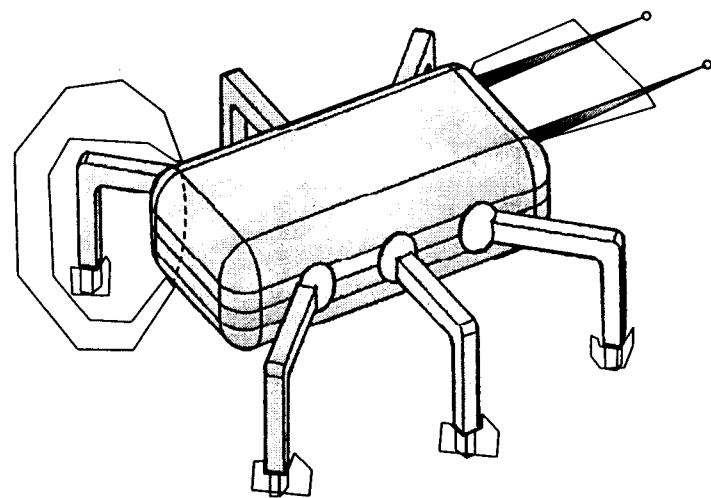
NARROW FOOTPRINT



WIDE FOOTPRINT

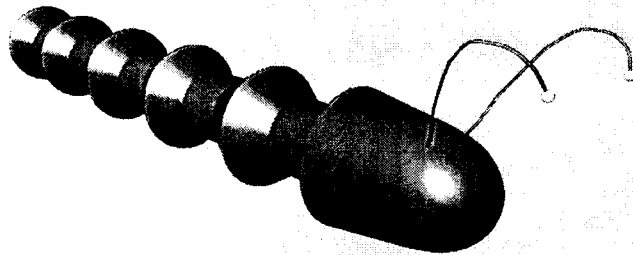


SHORT LEG

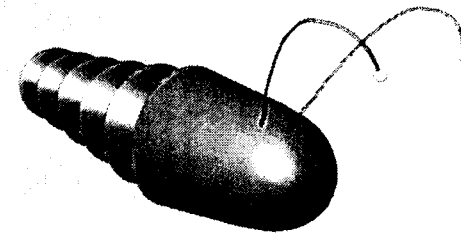


LONG LEG

WORM ROBOT FOR IN-SITU EXPLORATION



EXTENDED CONFIGURATION



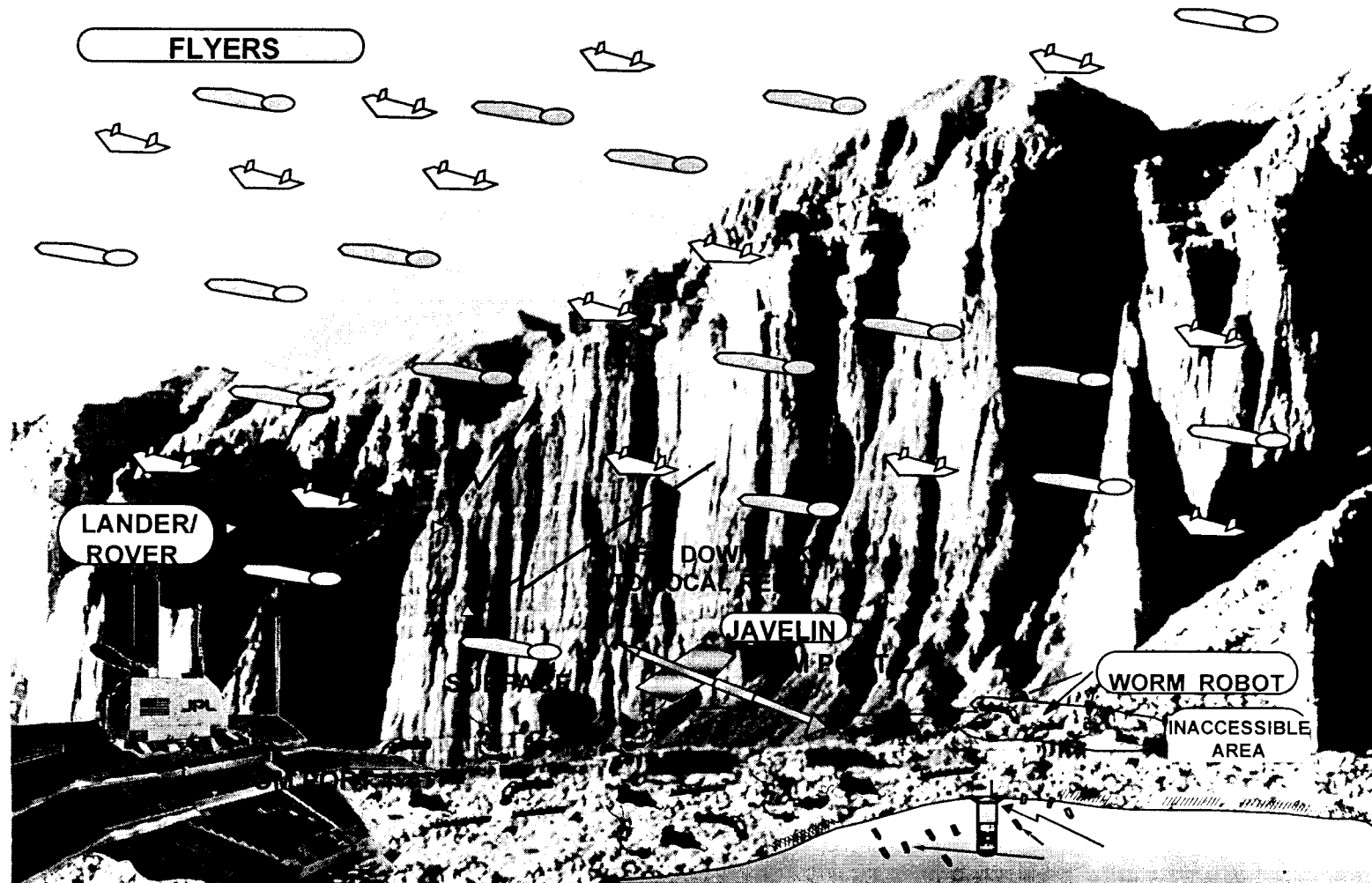
CONTRACTED CONFIGURATION

***Z. Gorjian and S. Thakoor, "Biomorphic Explorers Animation Video", 1st NASA/JPL WORKSHOP ON BIOMORPHIC EXPLORERS FOR FUTURE MISSIONS, August 19-20, 1998; Jet Propulsion Laboratory, Pasadena, CA**

Biomorphic Flight Systems

- **Extended reach over all kinds of terrain**
- **Unique perspective for IMAGING, SPECTRAL SIGNATURE, ATMOSPHERIC MEASUREMENTS**
- **Deploy Payloads**
- **Many flyers work in cooperation with larger UXV'S to enable new missions to ENABLE currently UNATTAINABLE MISSIONS**

ROBOTIC ECOLOGY FOR MARS



COOPERATIVE OPERATION OF LANDER, ROVER, AND A VARIETY OF INEXPENSIVE BIOMORPHIC EXPLORERS WOULD ALLOW COMPREHENSIVE EXPLORATION AT LOWER COST WITH BROADER COVERAGE.

KEY RESEARCH AREAS TO OBTAIN BIOMORPHIC EXPLORERS

•POWER SOLUTIONS

- RESOURCEFUL UTILIZATION OF NATURAL RESOURCES
 - SOLAR ENERGY, conventional
 - ATMOSPHERIC, wind, C,H,N,O resources
 - OCEAN RESOURCES
- MUTUALLY BENEFICIAL CO-EXISTENCE
(aerial/surface/subsurface systems)
- OUT OF THE BOX EFFICIENT ENERGY CONVERSION & GENERATION TECHNIQUES
 - PHOTOSYNTHESIS
 - ATP-ADP , storage - burst energy release

•MOBILITY INNOVATIONS: ADVANCED ACTUATORS, BIOMECHATRONIC DESIGNS

•SENSOR SUITES/FUSION - BIO-INSPIRED:

•ADAPTIVE CONTROLS/DISTRIBUTED CONTROLS: NEURAL CONTROLLER adjusts to real time input/situation: ADAPTABILITY, LEARNING, FAULT TOLERANCE

•COMMUNICATIONS

- self organising, dynamically reconfiguring multi hub/multinode organization
- em, accoustic, chemical, out of the box bio-inspired communication techniques and strategies

SCIENCE APPLICATIONS

....WHICH WOULD BE ENABLED/ENHANCED BY SUCH EXPLORERS.....

- **VALLES MARINERIS EXPLORATION**

- ONE SINGLE SITE RICH IN GEOLOGIC UNITS
- STUDY STRATIGRAPHIC COLUMN TOP TO BOTTOM
ALONG THE CANYON WALL
- OPTIMUM SCIENCE SAMPLE SITE

....imager, temperature sensor, pressure sensor, sniffer: e-nose, individual gases, elements, etc.

- **SCOUTING FOR CONDITIONS COMPATIBLE WITH LIFE TO LEAD US TO THE SPOTS THAT MAY HOLD SAMPLES OF EXTINCT/EXTANT LIFE**

- WIDE-AREA SEARCH WITH INEXPENSIVE EXPLORERS EXECUTING DEDICATED SENSING FUNCTIONS

....Individual gases, sniffer: e-nose, chemical reactions, pyrotechnic test, elements, specific amino acids, signatures of prebiotic chemistry, etc.

- **GEOLOGICAL DATA GATHERING:**

- DISTRIBUTED TEMPERATURE SENSING
- SEISMIC ACTIVITY MONITORING
- VOLCANIC SITE

....Multitude of explorers working in a cascade or daisy-chain fashion cooperatively to fulfill task

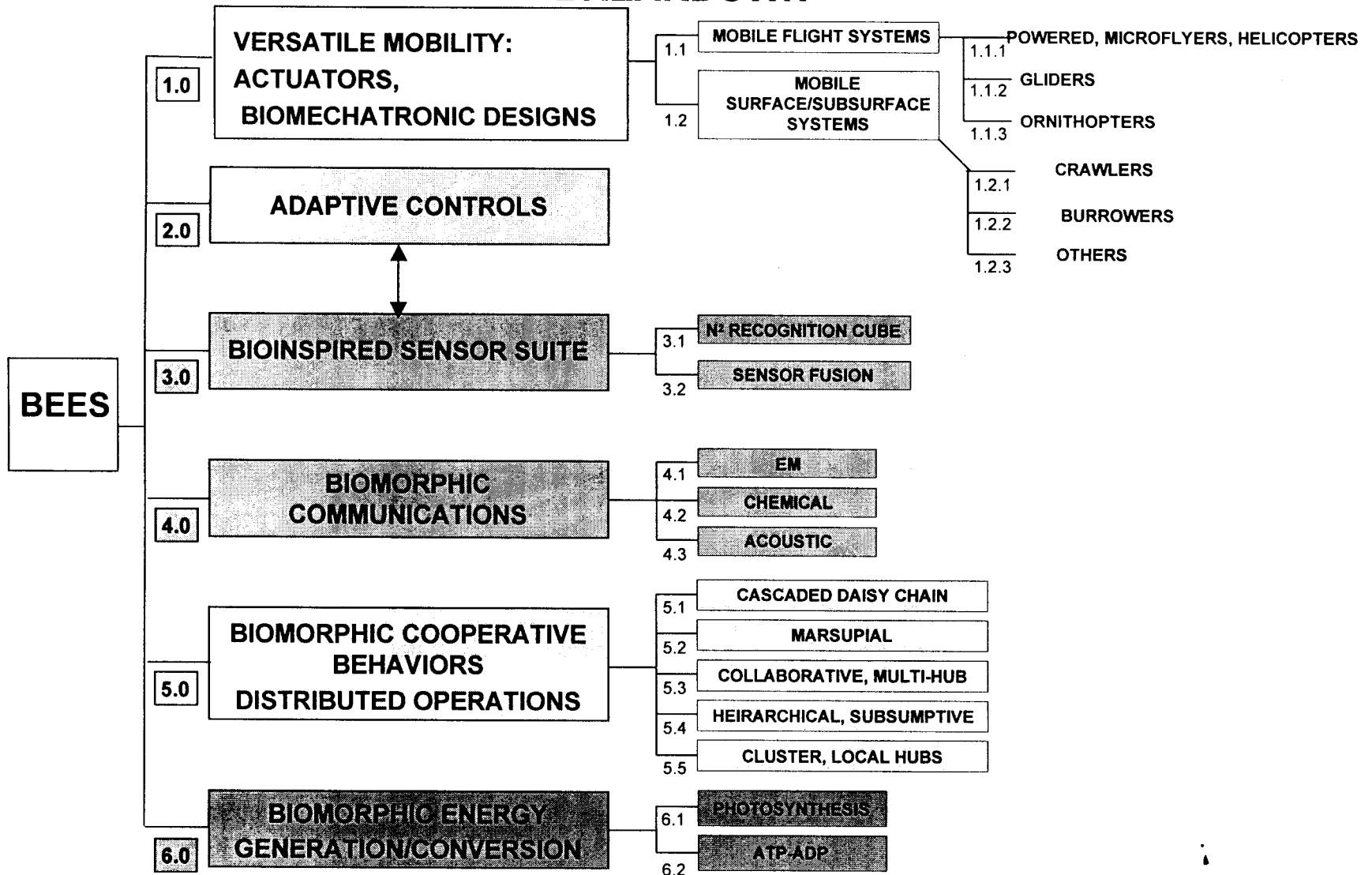
SCIENCE APPLICATIONS

- **ATMOSPHERIC INFO GATHERING**
- **DISTRIBUTED MULTIPLE SITE MEASUREMENTS**
- **CLOSE-UP IMAGING, EXO BIOLOGY SITE SELECTION**
- **DEPLOY PAYLOAD: INSTRUMENTS/CRAWLERS**
- **SAMPLE RETURN RECONNAISSANCE**

Applications (Dual Use NASA & DoD)

- **Distributed Aerial Measurements**
 - Ephemeral Phenomena
 - Extended Duration using Soaring
- **Delivery and lateral distribution of Agents (sensors, surface/subsurface crawlers, clean-up agents)**
- **Close-up Imaging, Site Selection**
 - Meteorological Events: storm watch
 - Reconnaissance
 - Biological Chemical Warfare
 - Search and Rescue etc
 - Surveillance
 - Jamming

BIOMORPHIC EXPLORERS (BEES) SUBSYSTEMS BREAKDOWN



Enabling Processor for ATR

BIOLOGICAL
NEURAL
NETWORK

OBJECT RECOGNITION,
FACE RECOGNITION



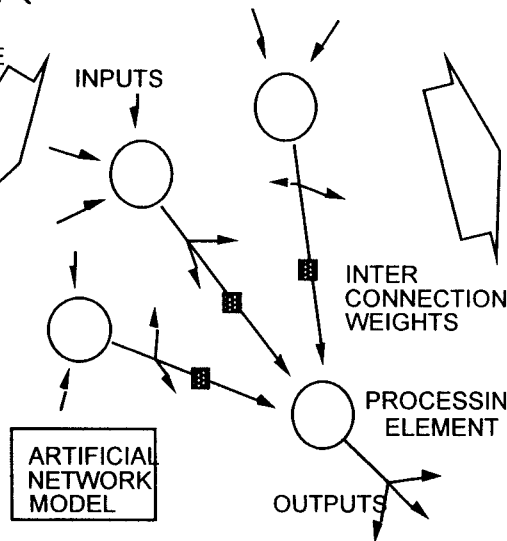
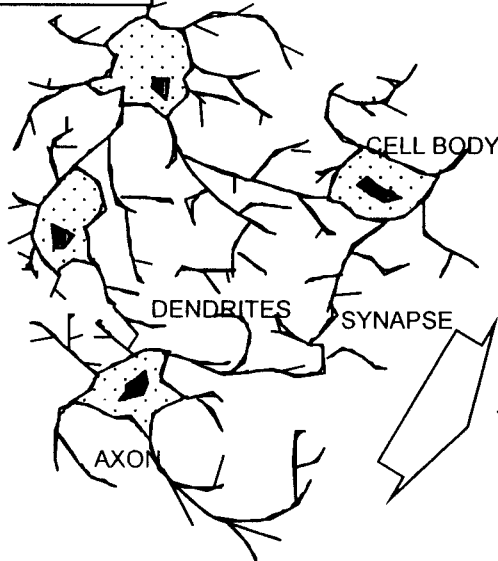
Input to

3D Artificial Neural Network
(3DANN)



64 Analog Outputs

Joint Strike Fighter



10 gm, 5 cc, 2 W

On-chip IR detector

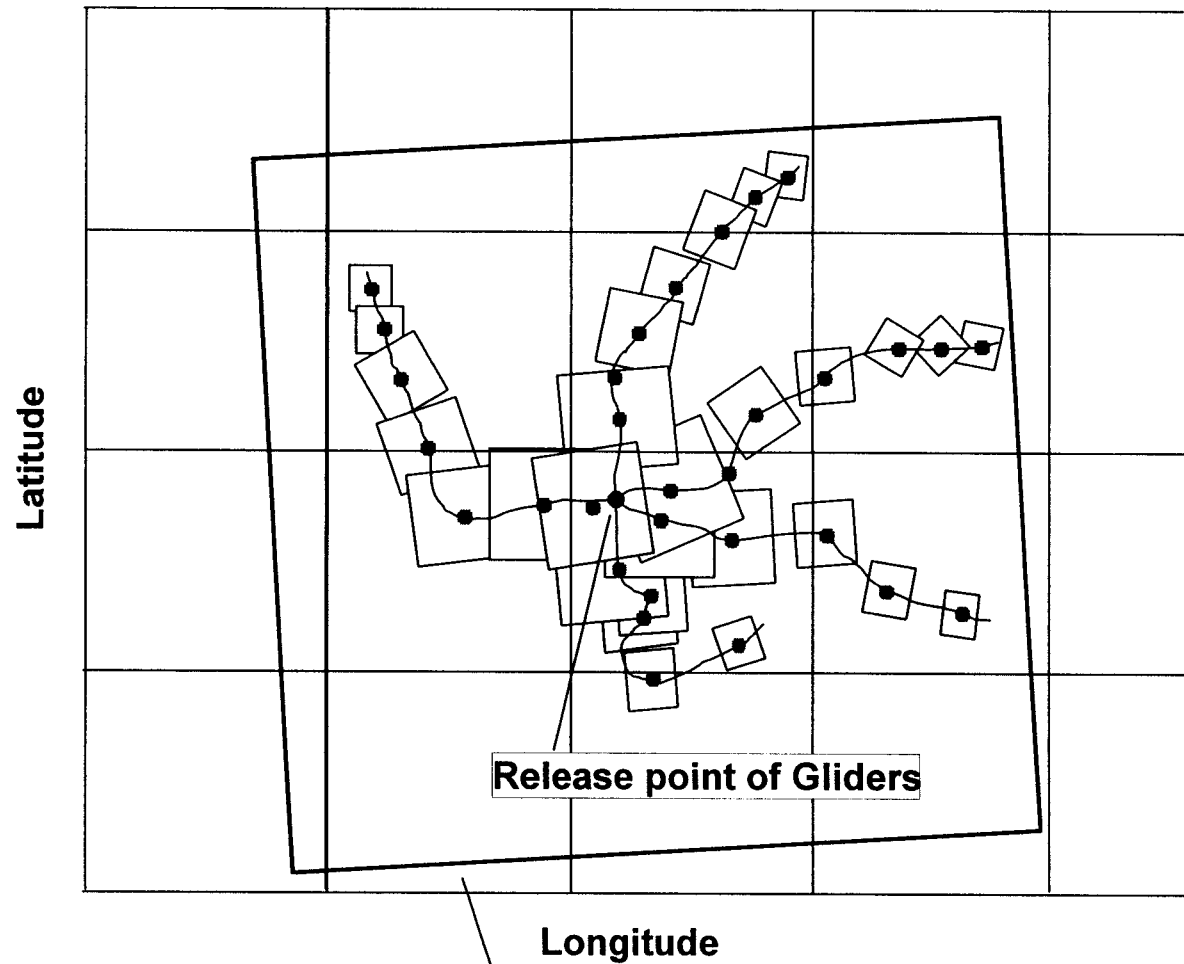
1 trillion 8-bit multiplies/sec

270 million template matches/sec

Compute power greater than fast supercomputer

JPL neural network chip design enables the 3DANN technology that delivers unprecedented processing speed for ATR: (64 convolutions of 64x64 masks in 16 msec vs. 2 hours on state-of-the-art workstations)

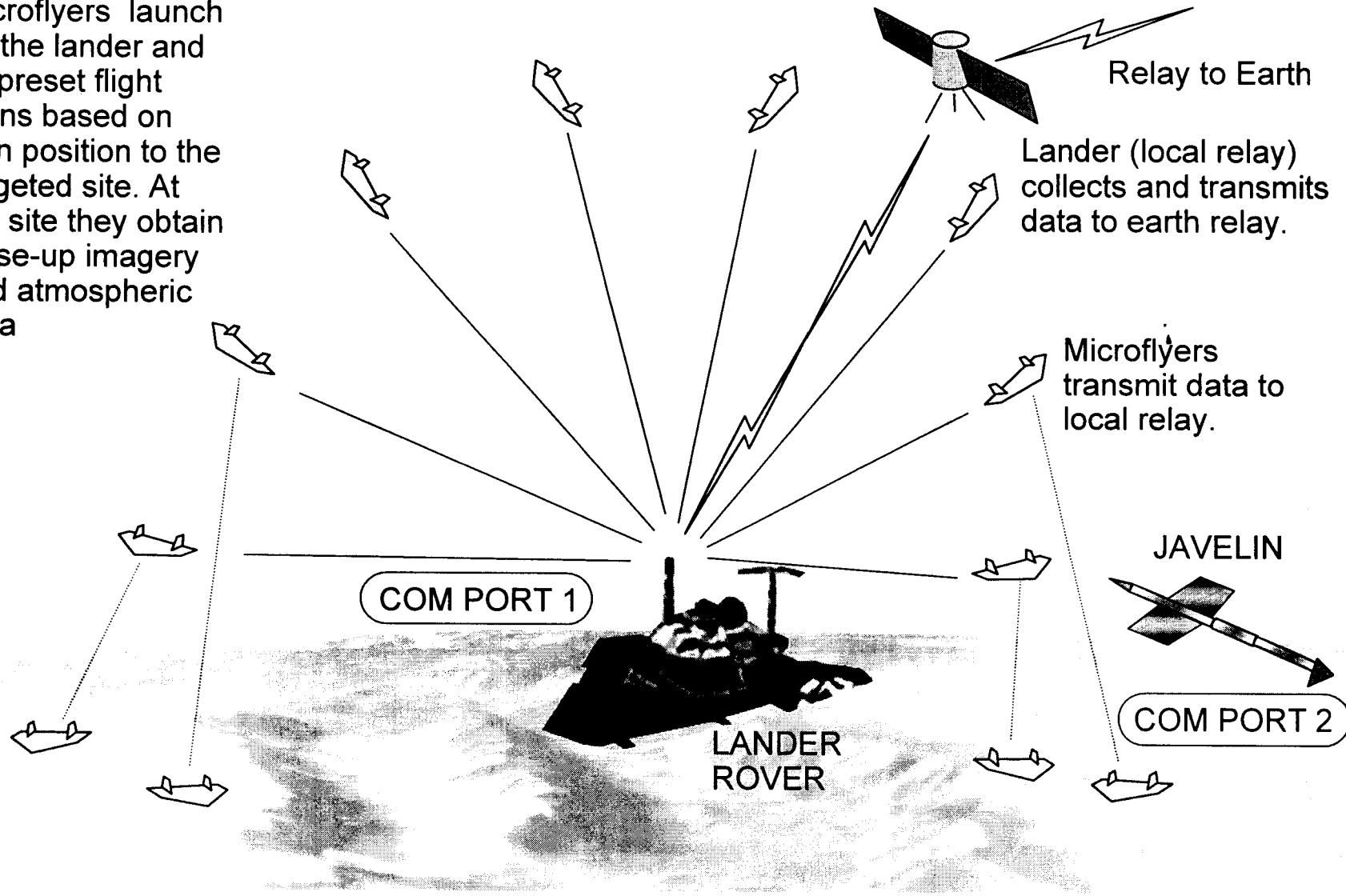
Footprints of Descent Images



Context frame acquired by carrier vehicle, 100 km x 100 km area

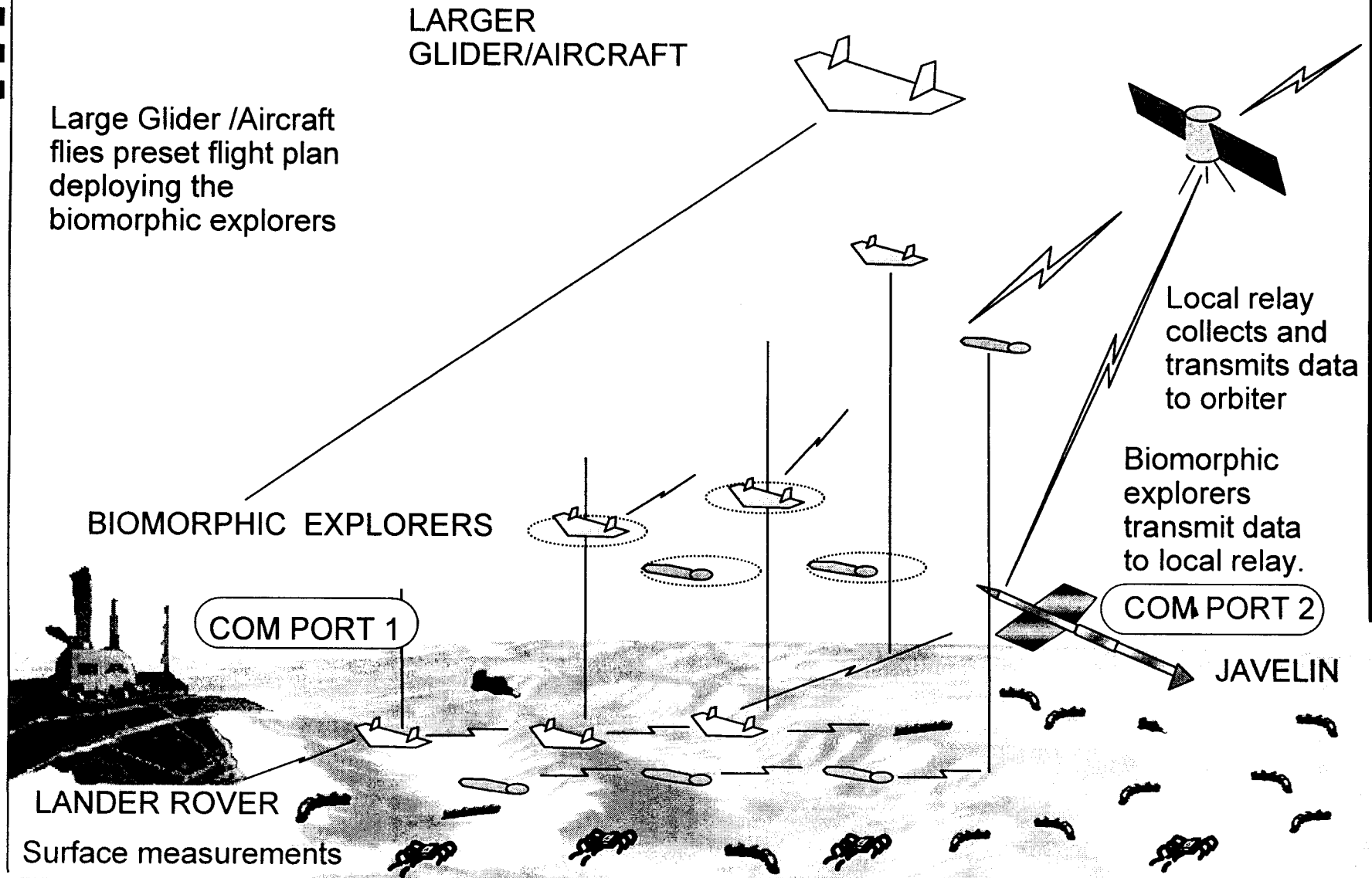
Surface Launched Microflyers for Reconnaissance Missions

Microflyers launch off the lander and fly preset flight plans based on Sun position to the targeted site. At the site they obtain close-up imagery and atmospheric data

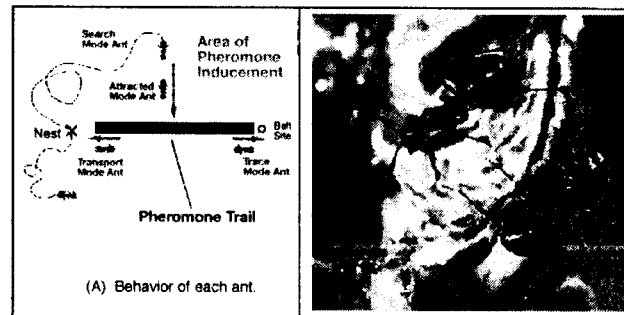


BIOMORPHIC EXPLORERS

BiomorphicExplorer Deployment Concept:
missions use potential energy: deployed from existing craft at high altitude

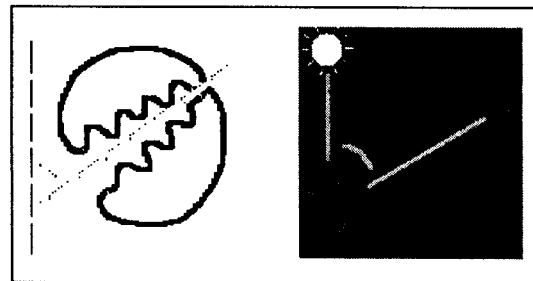


Insects operating cooperatively :



Nakamura and Kurumatani, 1995
Kubo, 1996

Ants' elaborate communication method with pheromone trails



Karl von Frisch, 1965
Wehner and Rossel, 1985
Barbara Shipman, 1997

Honeybee's recruitment dance with the sun as a celestial reference

BIOMORPHIC EXPLORERS

- **PAYOFF**
- **BIOMORPHIC EXPLORERS, IN COOPERATION WITH CURRENT EXPLORATION PLATFORMS CAN ENABLE**
 - **EXPLORATION OF CURRENTLY INACCESSIBLE AND/OR HAZARDOUS LOCATIONS**
 - **MUCH BROADER COVERAGE OF EXPLORATION SITES**
 - **EXPLORATION AT LOWER COST**

BIOMORPHIC EXPLORERS

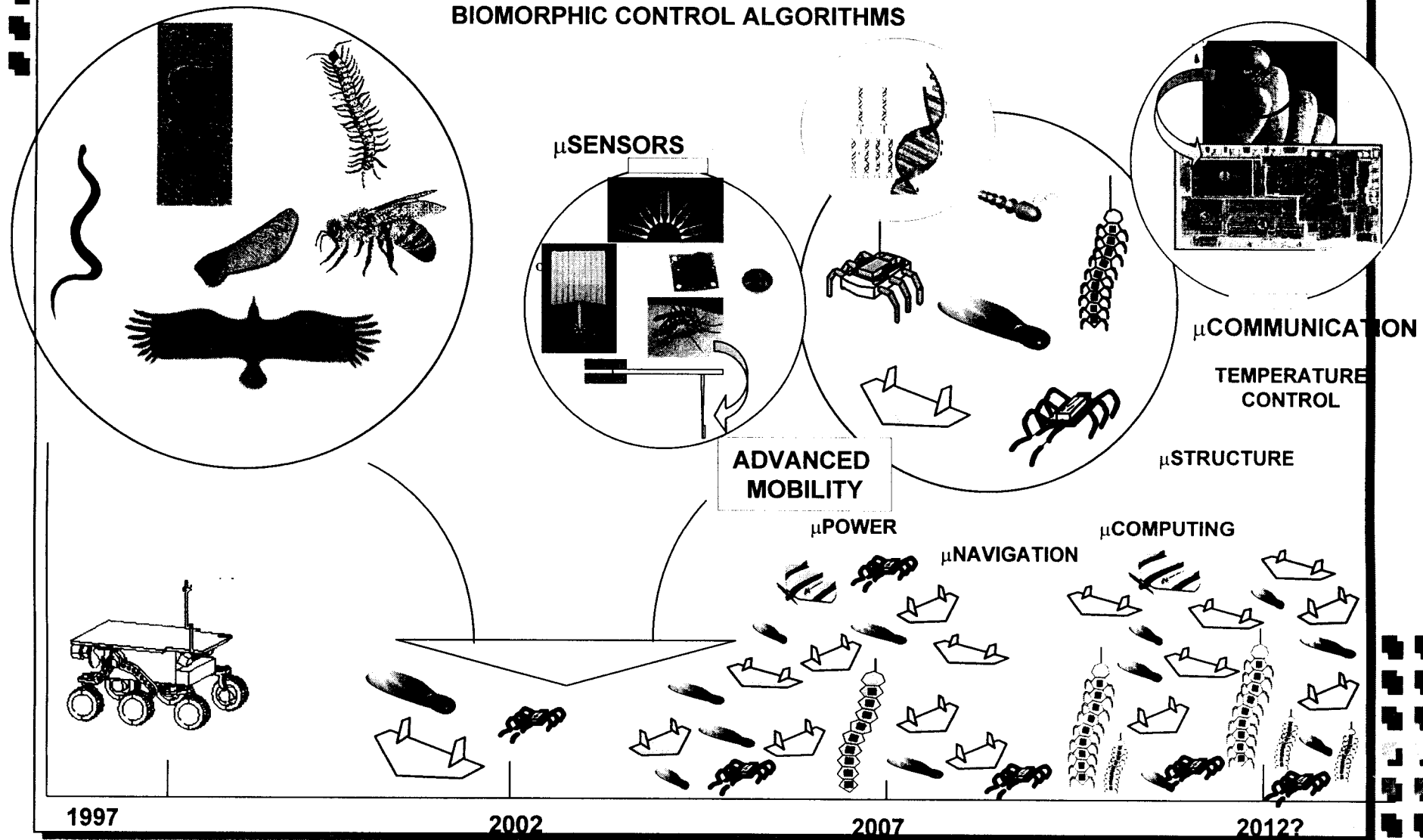
SUMMARY & ROADMAP

Enabling better spatial coverage and access to hard-to-reach and hazardous areas at low recurring cost

INSPIRATION

BIOMORPHIC COOPERATIVE BEHAVIOR BIOMORPHIC CONTROL ALGORITHMS

IMPLEMENTATION



***This work is sponsored by the
National Aeronautics and Space Administration***